ROLES OF SOME PARAMETERS ON LAVA FLOW MORPHOLOGIES. H. Miyamoto[1] and S. Sasaki[1], [1]Geological Institute, Graduate School of Science, University of Tokyo, Tokyo 113, Japan: mhideaki@geol.s.u-tokyo.ac.jp.

Summary

To clarify the roles of some parameters on lava flow morphologies, we have developed a three-dimensional numerical simulation model of lava flow and done a number of calculations with various values of parameters. Our preliminal results of calculations suggest that the length of lava flow is, as expected, a function of rheological properties of lava flow, eruption rate, slope angle, and cooling efficiency. The relationship of these parameters and morphologies of lava is not simple, which implies that we could not constrain rheological properties or eruption rate from the length of lava flow alone. On the other hand, the width of lava flow is mainly controlled by yield strength and eruption rate. Hense we consider that the width of lava flow is the most important key to estimate eruption rate.

Introduction

The existence of very long lava flows on Mars and Venus has been promoted attempts to relate lava flow length to the rheological properties of lava and eruption rate [e.g., 1, 2, 3]. The final shape of lava flow is thought to be controlled by viscosity, yield strength of lava, topographic features, eruption rate and erupted volume, cooling efficiency, and so on. Since most of these parameters controlling flow shape should change with time and place, there were several attempts to find the most effective parameter that governs the flow shape and relationships among the parameter and the flow morphology. However, except for the channel flow, the most effective parameter and relationships between the parameter and flow morphology is not well understood, even empirically [4, 5]: the existing model suggest that the lengths of the long lava flow are regulated by eruption rate [6], erupted volume [7], or rheological properties [1]. It is unclear which one is the most potent parameter. Therefore, at this time it is not easy to constrain rheological properties or eruption rates of lava flows from their morphologies. To understand role of each parameter on lava flow morphologies, it is necessary to develop a general model of lava flow motion. Analytical two-dimensional model could not explain lateral and longitudinal spread of lava flow, and isothermal model could not explain morphological effects of rheological properties that would change in time and place. Here, we take a three-dimensional numerical simulation approach to understand roles of parameters on lava flow morphologies.

Outline of the Method

There were several attempts of numerical simulations of lava flows [e.g., 8,9,10]. These models could roughly reproduce final shapes of lava flows, but are not precise enough for our purpose. That is because they used oversimplified mathematical models, since most of their goal is to make hazard maps in short calculation time. However, among them, the method by Ishihara seems to be more realistic, and has a great advantage to examine flow shape except for two problems. One is that it cannot calculate flows on a plane whose angle is less than about 5 degree, and further it cannot calculate flows longer than several km because of the anisotropy of their calculation method. Then, we improved their method for two points: we used a new basic equation of flow motion which consider the pressure driven flow to examine flows on a slightly inclined or flat plane, and improved the calculation method to keep isotropy.

Lava flow is known to behave as a Bingham fluid which is characterized by yield strength and plastic viscosity. We assume that a lava flow is a Bingham fluid, and that it flows as an incompressible laminar flow. These assumptions are widely made for analytical model of lava flow. Ishihara uses a downslope model of Bingham fluid derived by Dragoni [11], though this model is valid only when the plane beneath lava is inclined. In order to make the calculation possible when the slope is flat, we consider a pressure driven flow on this model. From the newly introduced equation of motion, which is a sort of steady state Navier-Stokes equation, and from the assumption of Bingham fluid, we derived a flow rate per unit width, which is the basic equation of our simulation code. Using this equation we calculate flows between nearest neighbor cells and pile up them for every cell.

Heat of lava flow is carried in accordance with the flow motion. Temperature of the lava in a cell is considered as isothermal: vertical temperature variation is neglected. For the cooling mechanism, we consider the radiative heat loss only from the surface of the flow, but the effect of conduction to the ground and to the atmosphere is neglected. Radiative heat loss of thermally mixed case is the extreme case because lava tubes and conductive lava crust actually lower the heat loss. Therefore, we introduced a parameter which is called cooling efficiency. It represents a fraction of exposed inner hot core and cool crust at the lava surface, and its range is from 0 (without cooling) to 1 (without crust).

The method of Ishihara is a kind of cellular automata method which is known to be strongly dependent on mesh shapes: flow on a flat plane spread to form rectangle shape though it should spread axisymmetrically. This problem affects the results significantly, and become a serious problem especially for calculations of large scale lava flows. In order to remove this problem, we consider a cellular automaton which has randomized representative points. We calculate all flows between the central cell and neighbor cells whose representative point is not distant the width of cell from the representative point of the central cell. Under this method, we can get perfectly mesh free results and can calculate large scale lava flows without numerical instabilities in a realistic calculation time [12].

Our method is validated against the steady state solution of isothermal Bingham fluid by Hulme [1] for two dimensional and isothermal flows, and by application to the observed actual lava flow.

Results and Discussion

The shape of small scale lava flow, especially the width of lava flow, seems to be controlled by the topographic features like valleys. However, as for large scale lava flows like flood basalts, small topographic features are thought to have scarcely affected the morphology of lava flows. Therefore it would be more meaningful to calculate large scale lava flows on a gentle slope plane. We calculate with various values of parameters to confirm if small change of some parameters could affect final morphologies. Here is the preliminary summary of the quantitative relationship between physical parameters and morphologies.

Rheological properties: The effect of viscosity and yield strength on length, width, and thickness of lava flow are summarized in Fig. 1a. As expected, yield strength is very important for flow morphology: it significantly affects length, width, area, and thickness. Smaller yield strength makes lava flow wider, longer, and thinner. On the other hand, viscosity does not largely affect width and thickness of lava. Actually, when viscosity is small, the lava flows faster, and therefore, the flow becomes longer and a little thinner, but the width of lava is not largely affected by viscosity.

Eruption rate: Calculation results with various eruption rates and constant erupted volume of lava are summarized in Fig. 1b. The eruption rate strongly affects the flow morphology: with increasing eruption rate, lava becomes wider and thinner. The decrease in length at higher eruption rate is due to the change of the controlling factor of the length. With the eruption rate below $10^7 m^3/s$, the width of lava is relatively narrow which means that the length of lava is mainly controlled by cooling processes. However, with eruption rate heigher than $10^7 m^3/s$, the width of lava becomes relatively wider and the thickness becomes significantly thinner, the length of lava is limited by their volume. This means that the eruption rate cannot be uniquely known from the length of lava alone. To estimate the eruption rate, we have to know the width of lava flow.

Slope angle: We also examined the effect of slope angle. Fig. 1c shows the morphologic change with slope angle. Note that the slope angle is small: from 0.01 to 1.0 degree. However, the length of lava flow is largely affected by the angle.

Cooling efficiency: Cooling is one of the most important processes for flow morphology. We take the radiative heat loss into account, and considered development of the crust by using cooling efficiency whose value is from 0 (without cooling) to 1 (no crust). As predicted, the length of lava is largely affected by cooling efficiency. However, the width change is not so serious against cooling efficiency.

Thus we ensured that the length of lava flow is controlled by rheological properties, eruption rate, slope angle, and cooling efficiency. The relationship between these parameters and lava flow morphologies are not simple and they interact each other. For this reason, we could not constrain any parameters of lava flow only from their length. On the other hand, the width of lava flow is slightly controlled by rheological properties and cooling efficiency, but mainly controlled by eruption rate and yield strength. Therefore, we can deduce that the width of lava is the most important key to estimate the eruption rate.

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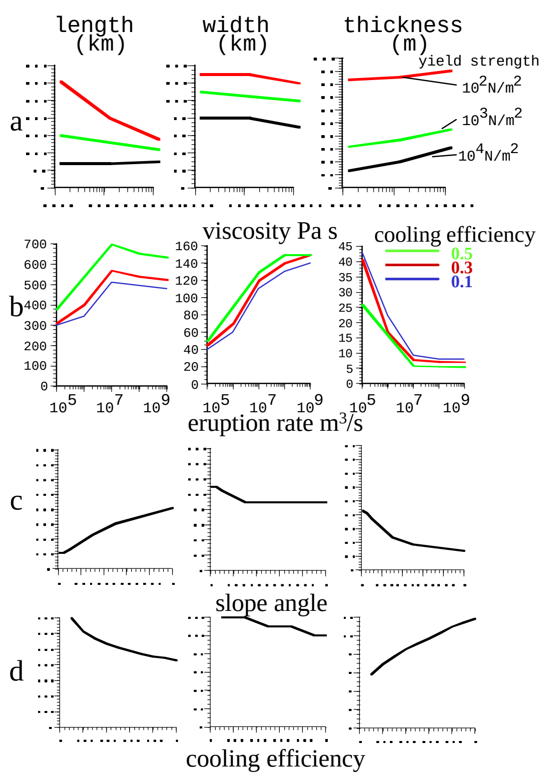

Fig. 1. Effects of parameters on standard basaltic lava flow: calculation results with various viscosity and yield strength (a), eruption rates (b), slope angles (c), and cooling efficiencies (d).